NASA Freeform Fabrication Facilities

Ken Cooper - MSFC

NASA and RP: History

- **NASA rapid prototyping labs have grown to include 8 major technologies**
  - **Selective Laser Sintering, Fused Deposition Modeling, Laminated Object Manufacturing, Stereolithography, MultiJet Modeling, 3D Printing, Electron Beam Welding & Laser Engineered Net Shaping**
- **Other processes with promise for In-Space Fab have developed as well**
  - **Laser Precision Metal Deposition, Ultrasonic Object Consolidation, Precision Optical Manufacturing**
- **NASA has done work to apply RP to manufacturing in microgravity applications**
  - **Examined and tested existing RP systems for theoretical functionality without gravity**
  - **Proofed machine against gravity by rotating RP machine and building parts free-hanging without support fixtures.**

Technology Definitions

- Fused Deposition Modeling (FDM) is an extrusion-based process for depositing thin layers of polymer to form a solid model.
- Selective Laser Sintering (SLS) forms parts in layer-wise fashion in a powder bed of polymer, sand, or polymer-matrix metal.
- Laser Engineered Net Shaping (LENS) and Precision Optical Manufacturing (POM) deposit metal powder into a high-powered laser beam on a moving substrate to form solid metal parts.

Technology Definitions

- Electron Beam Welding (EBW) is high intensity welding process used in conventional joining applications. LaRC is conducting research in applying the process to forming net-shape parts, as well as potential hand-held repair operations for space.
- Ultrasonic Object Consolidation (UOC) utilizes solid-state joining techniques to deposit layers of tape to form solid aluminum parts. Solidica developed the technology and is working under a NASA SBIR to develop a filament-based system that will have potential for application in microgravity.
- Laser Precision Metal Deposition (PMD) deposits spooled flat wire into a laser beam to form up solid metal parts. The part/repair area height is determined by number of layers.

Remote Manufacturing Via Rapid Prototyping Techniques:

RP Technologies

- FDM – Polymer, Green Ceramics
- SLS – Polymer, Polymer Matrix Steel
- LENS – Steels, Nickels, Titanium
- EBW – Titanium, Aluminum
- UOC – Aluminum
- PMD – Carbon Steel

6/13/99

RP Technologies at NASA

	LaRC	MSFC	GRC	ARC	JSC
FDM	X	X	X		X
SLS		X	X	X	
SLA	X	X	X		
LOM		X			
3DP	X	X			
LENS		X	X		
MJM	X	X			
EBW	X				

Directives

- From **NRA 01-OBPR-08** : “For the space program, free-form fabrication provides a venue for *in-situ* production of replacement parts during long duration missions, assembly, and repair. This capability to manufacture components during a mission will be an essential element to the human exploration and development of space.”
- The **National Research Council**, in its report entitled “Microgravity Research in Support of Technologies for the Human Exploration and Development of Space and Planetary Bodies” cites the “considerable potential for the extraterrestrial production of spare parts” utilizing rapid prototyping or “direct manufacturing”.
- An objective of the **HEDS Technology Commercialization Initiative**, WBS 2.1: Develop and validate the technology to utilize local resources, such as Regolith/Minerals, Ices and Atmosphere--in order to produce, process and deliver consumables; fabricate key physical structural systems/elements from local materials; enable local fabrication of selected "finished products" and/or "end items"

NASA's Current Position

- **Reduced gravity RP feasibility flight demonstration on KC-135 completed recently.**
  - **NASA joint project with Milwaukee School of Engineering**
  - **Were able to fabricate 7 different geometries, including hollow and free-hanging structures.**
  - **The rapid prototyping system functioned properly during the reduced gravity portions of flight.**
- **Conclusion: Feasibility of fabricating parts using rapid prototyping techniques in reduced gravity situations was successfully demonstrated, with results even better than expected.**
  - **Free hanging structures non-producible in gravity were fabricated easily during the flight.**

NASA's Current Position

- **Based on what we know now, we see that RP will provide excellent processes for remote manufacturing in microgravity, including:**
  - **Polymer part fabrication on board spacecraft**
  - **Metal hardware construction in flight (spares reduction)**
  - **Existing metallic hardware repair in flight**
  - **Spacecraft hull repairs in orbit**
  - **In situ manufacturing capability on moon or Mars**
- **The RP Processes we may use in space**
  - **Fused Deposition Modeling (FDM)**
  - **Ultrasonic Object Consolidation (UOC)**
  - **Electron Beam Manufacturing**
- **…And on the moon or Mars**
  - **Selective Laser Sintering (SLS)**
  - **Laser Engineered Net Shaping (LENS)**

Near Term Goals

- A successfully demonstrated flight-weight polymer RP system will be extensively tested on Shuttle prior to installation on Space Station.
- Meanwhile, NASA will continue to microgravity proof the direct metal RP processes, for metallic hardware fabrication on board the Shuttle and Space Station.
- Also, research continues on direct laser sintering of lunar glass and in-situ metals processing from Martian soil

Vision for the Future

- **In addition to on-board fabrication and repair systems, hand-held EVA units will be developed to repair external damage inflicted upon spacecraft hulls.**
- **Place larger fabrication systems in orbit as checkpoints for ships traveling to other planets. These systems can repair major damage too severe for the smaller on-board systems or hand-helds. Passersby may also store any extra build materials they have for future travelers.**
- **Direct laser sintering of glass or metals from processed lunar or Martian soil will provide in situ hardware fabrication capability, without carrying up build materials from Earth.**

Literature References

- “Rapid Prototyping at Zero Gravity for In-Flight Repairs and Fabrication on Space Station Freedom” – 1992 Solid Freeform Fabrication Proceedings; Roberts, Lomshek, & Brower
- P. Calvert and R. Crockett, AChemical Solid Free-Form Fabrication: Making Shapes without Molds@ *Chem Mater*. **1997** [9] 650-663.
- R.S. Crockett and P.D. Calvert, ARheology and Solid Freeform Fabrication: Modeling Material Flow in Deposition Techniques,@ in Proceedings of the 1997 Solid Freeform Fabrication Symposium, Austin, TX, August 1997.
- R.S., Crockett, B.D. Fabes, T. Nakamura, C.L. Senior, AConstruction of Large Lunar Structures by Fusion Welding of Sintered Regolith,@ in Engineering, Construction, and Operations in Space IV: Proceedings of Space 94, American Society of Civil Engineers, New York, 1994.

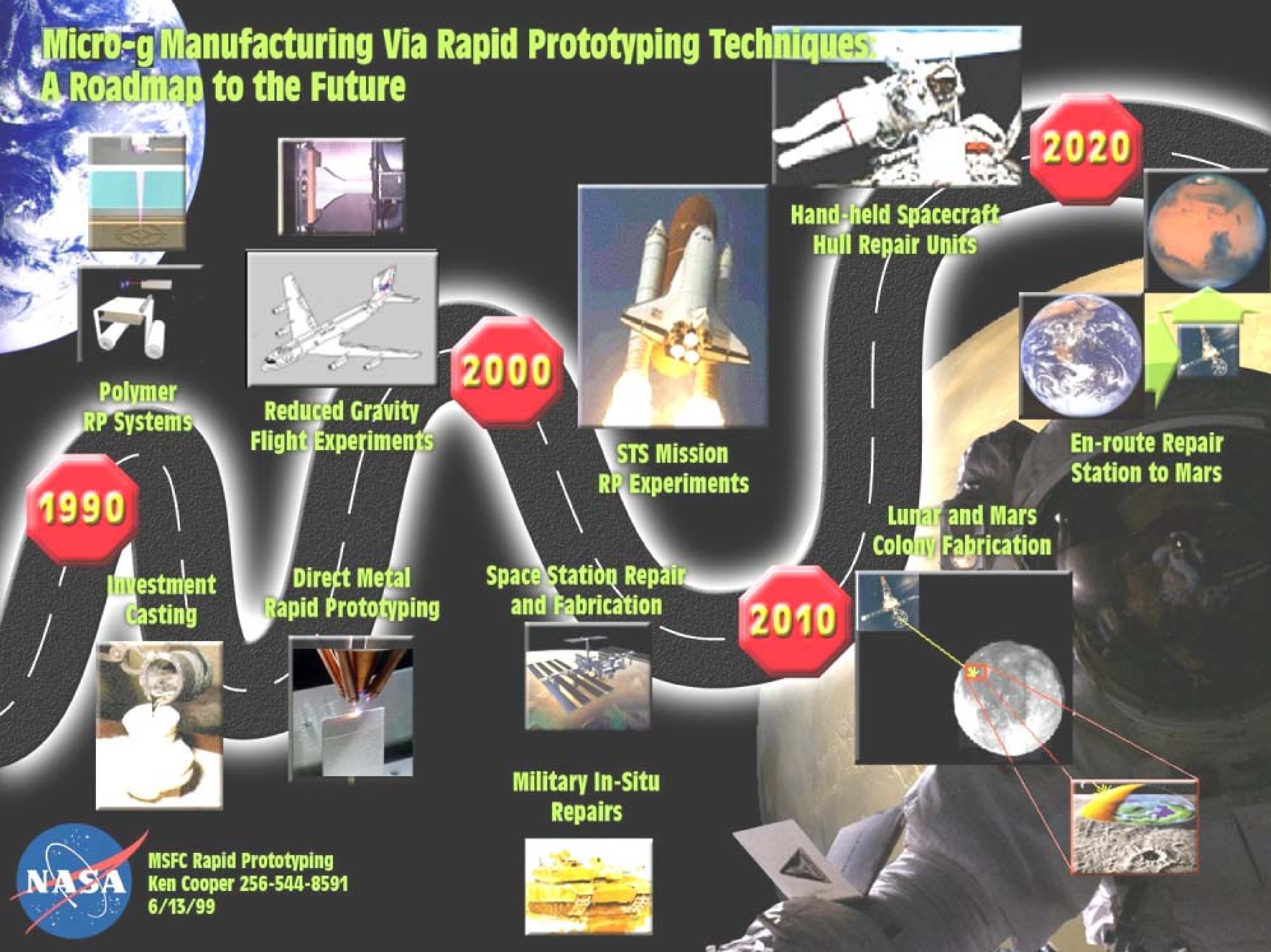
For More Information

MSFC Kenneth.G.Cooper@nasa.gov

LaRC Gary.A.Wainwright@nasa.gov

ARC Damon.L.Flansburg@nasa.gov

GRC Karl.D.Bergquist@nasa.gov



Micro-g Manufacturing Via Rapid Prototyping Techniques:
A Roadmap to the Future
1990
Polymer
RP Systems
Investment
Casting
Reduced Gravity
Flight Experiments
Direct Metal
Rapid Prototyping
2000
STS Mission
RP Experiments
Space Station Repair
and Fabrication
Military In-Situ
Repairs
2010
Lunar and Mars
Colony Fabrication
Hand-held Spacecraft
Hull Repair Units
2020
En-route Repair
Station to Mars
NASA
MSFC Rapid Prototyping
Ken Cooper 256-544-8591
6/13/99